

PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

A method and apparatus for producing X-Rays of particular Wave Lengths and Applications therefor

We, AUSTRALIAN ATOMIC ENERGY COMMISSION, a Statutory Authority of the Commonwealth of Australia, constituted under the Atomic Energy Act 1953—1958, of 45 Beach Street, Coogee, New South Wales, Commonwealth of Australia, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a method and apparatus for producing X-rays of particular wave lengths. The invention also relates to the use of the X-rays of particular wave lengths so produced, together with suitable detecting means, for various measurements and detecting applications.

The main object of the invention is to provide a source of X-rays of desired wave lengths. An important ancillary objective of the invention is to provide a method and apparatus for the measurement of the thickness of coatings (e.g. tinplate) and for analysis of the constituents of a material (e.g. of alloys, ores, elements in liquids, etc.).

In accordance with the invention there is provided a method of producing X-rays of particular wave lengths, in which a secondary material is caused to emit its characteristic X-radiation by excitation with fairly low energy (less than 500 kev) gamma radiation from a gamma ray emitting radioisotope (primary source) and the sources of primary and secondary radiation and a suitable gamma ray shield are so arranged that the secondary radiation emerges substantially free of the primary radiation, the radioisotope and the secondary material being so selected that the energy of at least some of the gamma rays is greater than that of the K (or L) absorption edge of the secondary material and the secondary material being one such that K (or

L X-rays produced have desired particular wave lengths. In certain circumstances the secondary material may itself constitute the gamma ray shield.

In accordance with the invention there is further provided a method for producing X-rays of particular wavelengths, in which a tertiary material is caused to emit its characteristic X-radiation by excitation with the characteristic X-rays of a secondary material, the secondary material having been caused to emit its characteristic X-radiation by excitation with fairly low energy (less than 500 kev) gamma radiation from a gamma ray emitting radioisotope (primary source), and the sources of primary, secondary and tertiary radiation and suitable γ -ray and X-ray shields are so arranged that the tertiary radiation emerges substantially free of both primary and secondary radiation, and the secondary radiation incident on the tertiary material is substantially free of primary radiation, the radioisotope, secondary and tertiary materials being so selected that the energy of at least some of the gamma rays is greater than the K (or L) absorption edge of the secondary material, and the secondary K (or L) X-rays are of energy greater than the K (or L) absorption edge of the tertiary material.

The invention also provides an apparatus for producing X-rays of particular wave lengths, comprising a secondary material and a gamma ray emitting radioisotope (primary source) to excite the secondary material by fairly low energy gamma radiation (less than 500 kev), the sources of primary and secondary radiation and a suitable gamma ray shield being arranged so that the secondary radiation emerges substantially free of the primary radiation, the radioisotope and the secondary material being so selected that the energy of at least some of the gamma rays is greater than that of the K

(or L) absorption edge of the secondary material and the secondary material being one such that K (or L) X-rays produced have desired particular wave lengths.

5 The invention moreover provides an apparatus for producing X-rays of particular wave lengths comprising a gamma ray emitting radioisotope (primary source), a secondary material which emits its characteristic X-radiation when excited by fairly low energy gamma radiation (less than 500 kev) emitted by said radioisotope, and a tertiary material which is caused to emit its characteristic X-radiation by excitation with the characteristic X-rays of the secondary material, the sources of primary, secondary and tertiary radiation and suitable γ -ray and X-ray shields being arranged so that the tertiary radiation emerges substantially free of both primary and secondary radiation and the secondary radiation incident on the tertiary material is substantially free of primary radiation, the radioisotope, secondary and tertiary materials being so selected that the energy of at least some of the gamma rays is greater than the K (or L) absorption edge of the secondary material, and the secondary K (or L) X-rays are of energy greater than the K (or L) absorption edge of the tertiary material.

30 The invention also provides method and apparatus as hereinafter more fully explained for measurement of the thickness of coatings and for analysis of the constituents of a material utilising the methods and apparatus hereinbefore defined.

35 An optional feature associated with the invention is the use of a filter placed in the secondary (or tertiary) X-ray beam to absorb a greater proportion of the higher energy K (or L) X-rays of the secondary (or tertiary) material than the lower energy K (or L) X-rays of the same material, e.g. to increase the ratio of K_{α} to K_{β} X-rays of the same material. The K shell absorption edge of the filter material must be of energy greater than that of the lower energy K (or L) X-rays but less than the energy of the higher energy X-rays.

50 Preferred embodiments of the invention will now be described in greater detail with reference to the accompanying drawings in which:

Fig. 1 shows, in cross section, one form of geometry of a source of X-rays of particular wave-lengths,

55 Fig. 2 is a perspective view of an alternative source of geometry,

Fig. 3 illustrates one shield assembly design, and

Fig. 4 illustrates an apparatus for coating thickness measurement.

It is well known that electromagnetic radiation of a given energy (wave length) incident upon matter may cause it to emit radiation of a different energy (wave length). This phenomenon is known as fluorescence, and the incident radiation and emitted radiation are sometimes described as primary and secondary.

In accordance with the present invention the primary radiation is fairly low energy gamma radiation from a radioisotope such as Gadolinium-153, Europium-155, Samarium 145, Iodine-125, Thulium-170 or Americium-241 to name several, although a limited number of other isotopes could be used. The energy of the secondary radiation will depend on the material on which the primary radiation is incident, but will be the characteristic X-rays from the K or L shell of the material. Any material may be used as this secondary source; and it may be desirable to use more than one material to obtain secondary radiations of different energies. For practical purposes the atomic number of the material should be 20 or higher. In general the material used will depend on the particular application intended for the radiation.

PRIMARY SOURCE

Principal requirements of the primary source are as follows:

- (i) the half-life to be as long as possible, so that frequent replacement of the primary material is not necessary.
- (ii) the energy of the gamma rays to be low so that the shielding required can be kept to a reasonable thickness.
- (iii) the energy of at least some of the gamma rays to be greater than that of the K (or L) absorption edge of the secondary material.
- (iv) to be used in a thin layer to prevent excessive internal absorption of the primary gamma radiation.

In seeking primary sources that satisfy these requirements one notes that it would not be necessary to use a secondary source if primary sources were available having the particular energy wanted.

The following radioisotopes meet the requirements for the primary source.

	Radioisotope	Energy of Principal gamma rays (kev)	Half-life
	Gadolinium-153	41, 97, 103	236 days
	Europium-155	43, 87, 105	1.7 years
5	Samarium-145	39, 61	1 year
	Iodine-125	27, 35	60 days
	Thulium-170	52, 84	127 days
	Americium-241	27, 33, 60 + others	458 years
10	Of these, the best are probably Gadolinium-153, Samarium-145 and Europium-155, because of their long half-lives and because very high specific activities may be obtained. If Thulium-170 is used, it is desirable to disperse the thulium in a low atomic number matrix, e.g. carbon, perspex, etc. so as to reduce the intensity of the high energy brems-strahlung component.		
15	SECONDARY MATERIAL		
20	Having selected the primary source, the secondary material must be such that its K (or L) shell X-rays are of the energy required. Thus to produce X-rays of energy suitable for use for tinplate measurement in accordance with the process described hereafter, X-rays of energy greater than 29.2 kev are required and so xenon, caesium, barium, lanthanum and higher atomic number materials may be used in the secondary material. Caesium (in the form of a caesium compound) is particularly suitable for this application, for highest sensitivity may be obtained when the K X-rays are of energy just greater than the tin K absorption edge. Xenon would be even more suitable if available in the form of a stable compound. Both primary and secondary materials must be available in a suitable physical form.		
25	PURITY OF THE X-RAY BEAM		
30	The purity of the X-ray beam (i.e. the ratio of the number of characteristic X-rays to the number of back-scattered gamma rays) depends on variables including:		
35	(a) the relative probabilities of photoelectric absorption and scattering of the gamma ray in the secondary material. For a particular secondary material, these probabilities depend on the energy of the gamma ray. Purity is highest when the energy of the gamma ray is just greater than the energy of secondary material K (or L) absorption edge.		
40	(b) the geometry of the primary source, shield and target material.		
45	(c) the thickness of the target material. For thin layers of target material, purity also depends on the material behind the secondary material (e.g. air, lead, etc.) and its geometry.		
50	GEOMETRY		
55	By suitably arranging the sources of primary		
60	and secondary radiation a device is obtained from which the latter emerges almost entirely free of the former. Most of the X-ray beam consists of characteristic X-rays of the secondary material, although some of the primary gamma rays will be scattered in the secondary material and so emerge with a different energy to that of the characteristic X-rays.		
65	One suitable geometry has been found in which a shield is placed in front of the radioisotope source. The secondary emitting material is in the form of a hollow truncated cone, the narrow end of which is situated behind the radioisotope source and the inclined portions extend beyond the shield. The inclined portions of the secondary material help to intercept any primary radiation not absorbed in the shield, and emit useful amounts of secondary radiation. This geometry is illustrated in Figure 1 wherein the radioisotope 1 contained in capsule 2 is positioned on a support 3 behind lead shield 5. The secondary material is in the form of a hollow truncated cone 4 and the primary radiation is illustrated by line 6 and the secondary radiation by line 7.		
70	Another source geometry is illustrated in Figure 2 wherein the secondary material 4 is arranged as a series of plates each backed by shield material 8 surrounding the capsule 2 containing the radioisotope 1. Also a top and bottom of the secondary material 4 backed by shield material 8 is placed above and below the shielded plates of secondary material previously referred to.		
75	Obviously a very wide range of source geometries is possible. The main point of design is that the secondary X-ray beam emerges almost entirely free of the primary gamma rays. However, a careful selection of variables (a) to (c) will ensure a high purity source.		
80	The shield in front of the source must be thick enough to absorb a large proportion of the gamma rays emitted by the radioisotope. If the efficiency of X-ray production is, e.g. 10%, the shield must reduce the primary gamma rays by a much greater factor, to ensure a low level of unwanted radiation. In addition to the shield in front of the source, it may be an advantage to place a further shield behind the secondary material, either directly behind it or at a distance from it, so as to reduce the intensity of the primary gamma rays transmitted through it. The result is a fairly compact source, of reasonable weight.		
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SHIELD BEHIND SECONDARY MATERIAL

In many cases purity may be enhanced if the secondary material is in the form of a thin layer and if the shield behind it is suitably designed. The secondary material layer is considered to be thin, if, by adding a further thickness of secondary material to the layer, there is an increase of backscattered gamma rays from the method or apparatus hereinbefore described.

There are various suitable arrangements for the shield behind the secondary material. Two arrangements are as follows:

- (i) the shield is designed so that the primary gamma rays which are not absorbed in traversing the secondary material are absorbed or scattered in the shield in such a way that most of the gamma rays scattered and fluorescent X-rays excited in the shield are absorbed again by the shield assembly. One shield assembly design is shown in Figure 3. It consists of a hollow cylinder 9 of material (e.g. lead) with an opening at one end, and hollow conical shields 10 and 11. In this assembly the conical shields 10 and 11 have their ends tipped with the same material as the secondary material as shown at 12. The conical shields prevent many of the gamma rays which have been scattered by air or the shield from escaping the shield assembly.
- (ii) the shield is placed directly behind the thin layer of secondary material. The shield material should be of atomic number higher than the secondary material, and the thickness of the secondary material layer should be sufficient to absorb almost all of the fluorescent X-rays

excited in the shield and which traverse the secondary material layer.

APPLICATIONS

A very wide range of applications of X-rays in accordance with this invention is possible. In combination with a means of detection of X-rays, such as an ion chamber, a scintillation counter, a proportional counter, a solid state detector, or a geiger counter, and with suitable shielding, the source constitutes an apparatus for many purposes.

Examples of possible applications are:—

- (i) measurement of coating thickness (weight per unit area), e.g. tinplate; silver weight per unit area on photographic films.
- (ii) analysis of the constituents of materials, e.g. of alloys, ores, elements in liquids.
- (iii) energy calibration source for various X-ray counters, e.g. proportional and scintillation counters, solid state detectors.

The particular application determines the intensity and energy of the K X-rays to be used, and consequently the activity of the primary source and materials for the secondary source. It also determines the arrangement of source shielding and the type of detector to be used.

Although the applications (i) to (iii) can be solved by more conventional methods, there are very significant advantages in using the present invention. Conventional methods include chemical techniques, X-ray devices (X-ray spectrometers, etc.) and techniques using beta ray excited X-ray sources. The following table lists some of the advantages of the new invention compared to more conventional techniques.

<i>Conventional Method</i>	<i>Advantages of new invention over Conventional Method</i>
X-ray tube device (Spectrometers etc.)	Cheapness, simplicity of equipment, source of X-rays inherently more stable, fully portable (e.g. may be used in the field for ore analysis)
Beta ray excited X-ray sources	Much higher efficiency in 0—100 kev range, and consequently smaller activities of radio-isotope required. Purity much higher, and so higher sensitivity possible for almost all X-ray fluorescence applications.
Chemical (including electrochemical)	Measurements can be made without contact with sample, e.g. possible to measure continuously on moving production lines (tinplate, etc.). Generally faster measurement.

EXAMPLES

The following examples illustrate some of the uses of the invention. Figure 4 illustrates the apparatus used in the examples for coating thickness measurement and alloy constituent analysis. As shown in Figure 4, the apparatus illustrated in Figure 1 comprising

the radioisotope 1, lead shield 5 and secondary material 4 is positioned within a lead block 13, a scintillation detector 15 is also positioned within the lead block 13. The material under test is designated 18 and the rays coming from the material 18 indicated by the line 14 pass through filter 16 and a thin crystal with

a beryllium window indicated by numeral 17 into the scintillation detector 15.

1. Coating thickness (weight per unit area) measurement

- 5 1.1. In the following examples an X-ray beam, having the selected energy spectrum produced by the method or apparatus hereinbefore described is projected onto the coating material and excites the fluorescent radiation of at least one constituent of the coating material. The intensity of this excited K shell X-radiation depends on the weight per unit area of coating and provides a means whereby the weight per unit area of the coating can be determined.

For the following examples, the accuracy to which the coating thickness may be determined depends on:

- 20 (a) the ratio of the intensity of coating material K X-rays to the intensity of the X-rays backscattered by the base material, both intensities as measured by the X-ray detection system.
- 25 (b) the change in intensity of the X-rays backscattered by the base material with change in weight/unit area of the base material.

If the thickness of the base material is known, then only (a) need be considered.

30 1.2 Tinplate thickness measurement

- For this measurement the isotope (primary) source was Gadolinium-153, and the secondary material caesium in the form of caesium chloride. The caesium K X-rays of energy about 31 kev were directed onto samples of tin coated steel having coating thicknesses between 0 and 1 lb. per basis box. The backscattered emergent tin K X-rays (energy ~ 25 kev) were measured by a scintillation counter (used without energy analysis). In each case the sodium iodide scintillation crystal, of thickness 0.025 inches, was covered by a 0.002 inch silver foil. The silver foil absorbs a greater proportion of the backscattered X-rays from the base plate than tin K X-rays, and so the sensitivity of the technique is enhanced.

- The base plate thickness was about 0.009 inch, and the ratio of backscattered count rate from steel with a 1.00 lb. per basis box coating to count rate from steel with no coating was 7.0 to 1. A 10% change in base thickness had only a small effect on backscattered intensity. The accuracy of measurement of tinplate thickness, including an allowance for a $\pm 10\%$ change in base plate thickness and a statistical uncertainty of 1% in measurement of count rate is 2.6% and 1.4% for tin layers of 0.25 and 1.00 lb. per basis box respectively.

1.3 Silver weight per unit area on photographic films, papers etc.

For this measurement the isotope (primary) source was Gadolinium-153, and the secondary material tellurium. The tellurium K X-rays of energy about 27 kev were directed on to photographic film stock having coatings containing between 0.2 and 2 grams of silver per square foot. The backscattered silver K X-rays (energy ~ 22 kev) were measured by a scintillation counter (without energy analysis). In each case the sodium iodide scintillation crystal, of thickness 0.025 inches, was covered by a 0.003 inch palladium foil. The palladium foil absorbs a greater proportion of the backscattered X-rays from the film base and surrounding materials than the silver K X-rays, and so the sensitivity of the technique is enhanced.

The relative backscattered count rates from a 0.008 inch base thickness having (a) a coating containing 2 grams of silver per square foot, (b) a coating containing 1.00 grams of silver per square foot, and (c) no coating was 16:9.1:1. The accuracy of measurement of silver weight per unit area, including an allowance for a $\pm 10\%$ change in base thickness and a statistical uncertainty of 1% in measurement of count rate, is 4.7% for 0.2 grams of silver per square foot and 1.4% for 2 grams of silver per square foot.

1.4 It is noted that the coating weight per unit area may be determined by another method in which the apparatus hereinbefore described is used, although no examples are given. In this case an X-ray beam, having the selected energy spectrum produced by the method or apparatus hereinbefore described is projected onto the sample and excites fluorescent radiation in the base material. The intensity of the emergent fluorescent beam depends on the thickness of the coating; both the incident exciting radiation and the emergent fluorescent radiation are partially absorbed in the coating so that the intensity decreases as the coating thickness increases. This provides a means whereby the weight per unit area of the coating can be determined.

2. Alloy constituent analysis

2.1 In the following examples an X-ray beam having the selected energy spectrum produced by the method or apparatus hereinbefore described was projected onto the alloy and excited the fluorescent radiation of the constituent to be analysed. The intensity of this excited K shell X-radiation depends on the abundance of the constituent to be analysed, and provides a means whereby this can be determined.

2.2 Cadmium content of zinc plates

For this measurement the isotope (primary source) was Gadolinium-153, and the secondary material tellurium. The tellurium K X-rays of energy about 27 kev were directed onto zinc plates containing less than 0.25% of cadmium by weight. The backscattered emergent cadmium K X-rays (energy ~23 kev) were measured with a scintillation counter (without energy analysis). In each case the sodium iodide scintillation crystal, of thickness 0.025 inches, was covered by a 0.003 inch palladium foil. The palladium foil absorbs a greater proportion of the backscattered X-rays from the zinc than cadmium K X-rays, and so the sensitivity of the technique is enhanced.

The ratio of backscattered count rates from a plate containing 0.243% by weight cadmium to a plate containing 0.056% by weight cadmium was 1.4:1, i.e. a change from no cadmium to 0.005% by weight cadmium will produce ~ 1% change in count rate.

2.3 Antimony content of lead plates

For this measurement the isotope (primary source) was Gadolinium-153, and the secondary material caesium in the form of caesium chloride. The caesium K X-rays of energy about 31 kev were directed onto lead plates containing between 0 and 3.2% by weight antimony. The backscattered emergent K X-rays (energy ~ 26 kev) were measured with a scintillation counter (without energy analysis). In each case the sodium iodide scintillation crystal, of thickness 0.025 inches, was covered by a 0.0025 inch cadmium foil. The cadmium foil absorbs a greater proportion of X-rays backscattered from the lead than antimony K X-rays, and so the sensitivity of the technique is enhanced.

The ratio of backscattered count rates from a plate containing 3.2% by weight antimony to a plate containing no antimony was 1.6:1, i.e. a change in antimony content from 0 to 0.05% by weight will cause ~ 1% change in count rate.

3. Energy calibration source for X-ray counters

The method and apparatus described hereinbefore have been used to calibrate accurately both proportional and scintillation counters, and are excellent for this purpose because of the high ratio of the number of fluorescent X-rays to backscattered gamma rays.

4. Quantitative analysis of elemental constituents of a solution

In the following example X-ray beams having the selected energy spectra produced by the method or apparatus hereinbefore described were directed toward a detector through a liquid sample, and by measurement of the absorption of each beam in the sample,

the concentrations of some of the constituents of the sample were determined. Small amounts of cadmium and silver as nitrates were dissolved in a known volume of water. Two sets of measurements were made (a) the absorption of the sample compared to the absorption by the same thickness of water was determined for X-rays with energy about 27.4 kev, (b) the absorption by the sample compared to the absorption by the same thickness of water was determined for X-rays with energy about 26.3 kev. In the former case, both silver and cadmium strongly absorb the X-rays since the energy of the X-rays is greater than both the cadmium and silver K shell absorption energies. In the latter case, the absorption per unit weight of silver is much greater than per unit weight of cadmium, because the energy of the X-rays (26.3 kev) is just greater than the silver K shell absorption edge, but just less than the cadmium K shell absorption edge. From the relative intensity measurements [i.e. (a) and (b)], and from mass absorption coefficients of the X-ray beams for silver and for cadmium determined experimentally, the cadmium and silver content of the solution was determined.

The primary source used was Thulium-170 (as thulium oxide dispersed in a beryllium oxide matrix and encased in a plastic material) and the secondary materials, in the form of hollow truncated cones, were (a) tellurium and (b) antimony. To eliminate most of the K β X-rays from the secondary X-ray beam, a 0.002 inch tin foil was placed over the open end of each truncated cone. A scintillation counter (without energy analysis) with a 0.025 inch thick sodium iodide crystal detected X-rays having traversed one centimetre of solution.

Separate measurements of absorption of each X-ray beam in several solutions of known cadmium content and several solutions of known silver content were made. In each case the absorption of the X-ray beam versus concentration was found to follow, within the limits of experimental error, the well known exponential law. From these measurements the experimentally determined mass absorption coefficients for these X-ray beams in cadmium and silver were (a) 34.6 and 32.4 cm² per gram and (b) 9.90 and 36.8 cm² per gram, where (a) and (b) correspond to the use of tellurium and antimony respectively for the secondary material. The absorption of the X-ray beam was assumed to be described by the following equations:

$$I = I_0 \exp [-(34.5 C_1 + 32.4 C_2) x] \quad 120$$

$$I^1 = I_0^1 \exp [-9.9 C_1 + 36.8 C_2 x] \quad 120$$

where:

(i) I/I_0 and I^1/I_0^1 are the respective ratios, in the cases of tellurium and antimony as the secondary materials, of the detected count rates of the X-ray beams after traversing equal

distances of sample solution and pure water.
(ii) C_1 and C_2 are the respective concentrations in grams per cc of cadmium and silver in the unknown sample.

- 5 (iii) x , the distance the X-ray beams traverse in the sample, is 1 cm.

By solving these simultaneous equations, the concentration of cadmium was found to be 9.90 mg per cc and of silver 10.6 mg per cc. The sample was chemically analysed, and the cadmium and silver concentrations were found to be 10.06 and 10.35 mg per cc respectively, i.e. an error of less than 2.5% in each case.

- 10 Although the foregoing illustrates a specific example, the X-ray absorption technique using X-ray beams having the selected energy spectra produced by the method or apparatus hereinbefore described may be used to identify a wide range of elements in solids and fluids and to determine quantitatively their concentrations. This may be done for one or more of a group of elements in a sample.

WHAT WE CLAIM IS:—

1. A method of producing X-rays of particular wave lengths, in which a secondary material is caused to emit its characteristic X-radiation by excitation with fairly low energy (less than 500 kev) gamma radiation from a gamma ray emitting radioisotope (primary source) and the sources of primary and secondary radiation and a suitable gamma ray shield are so arranged that the secondary radiation emerges substantially free of the primary radiation, the radioisotope and the secondary material being so selected that the energy of at least some of the gamma rays is greater, than that of the K (or L) absorption edge of the secondary material and the secondary material being one such that K (or L) X-rays produced have desired particular wave lengths.

2. A method for producing X-rays of particular wave lengths, in which a tertiary material is caused to emit its characteristic X-radiation by excitation with the characteristic X-rays of a secondary material, the secondary material having been caused to emit its characteristic X-radiation by excitation with fairly low energy (less than 500 kev) gamma radiation from a gamma ray emitting radioisotope (primary source), and the sources of primary, secondary and tertiary radiation and a suitable gamma ray shield are so arranged that the tertiary radiation emerges substantially free of both primary and secondary radiation, and the secondary radiation incident on the tertiary material is substantially free of primary radiation, the radioisotope, secondary and tertiary materials being so selected that the energy of at least some of the gamma rays is greater than the K (or L) absorption edge of the secondary material, and the secondary K (or L) X-rays are of energy greater than the K (or L) absorption edge of the tertiary material.

3. A method in accordance with claim 1

or claim 2 in which the secondary material itself constitutes the gamma ray shield.

4. A method in accordance with any one of claims 1 to 3 in which a filter is placed in the secondary and/or tertiary X-ray beam to absorb a greater proportion of the higher energy K (or L) X-rays of the secondary and/or tertiary material than the lower energy K (or L) X-rays of the same material.

5. A method in accordance with any one of claims 1 to 4 in which the radioisotope is selected from the group consisting of Gadolinium-153, Europium-155, Samarium-145, Iodine-125, Thulium-170 and Americium-241.

6. An apparatus for producing X-rays of particular wave lengths, comprising a secondary material and a gamma ray emitting radioisotope (primary source) to excite the secondary material by fairly low energy gamma radiation (less than 500 kev), the sources of primary and secondary radiation and a suitable gamma ray shield being arranged so that the secondary radiation emerges substantially free of the primary radiation, the radioisotope and the secondary material being so selected that the energy of at least some of the gamma rays is greater than that of the K (or L) absorption edge of the secondary material and the secondary material being one such that K (or L) X-rays produced have desired particular wave lengths.

7. An apparatus for producing X-rays of particular wave lengths comprising a gamma ray emitting radioisotope (primary source), a secondary material adapted to be excited by fairly low energy gamma radiation (less than 500 kev) emitted by said radioisotope, and a tertiary material which is adapted to emit its characteristic X-radiation by excitation with the characteristic X-rays of the secondary material, the sources of primary, secondary and tertiary radiation and suitable gamma ray and X-ray shields being arranged so that the tertiary radiation emerges substantially free of both primary and secondary radiation and the secondary radiation incident on the tertiary material is substantially free of primary radiation, the radioisotope, secondary and tertiary materials being so selected that the energy of at least some of the gamma rays is greater than the K (or L) absorption edge of the secondary material, and the secondary K (or L) X-rays are of energy greater than the K (or L) absorption edge of the tertiary material.

8. An apparatus in accordance with claim 6 or claim 7 in which the secondary material itself constitutes the gamma ray shield.

9. An apparatus in accordance with any one of claims 6 to 8 incorporating a filter which is placed in the secondary and/or tertiary X-ray beam to absorb a greater proportion of the higher energy K (or L) X-rays of the secondary and/or tertiary material than

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the lower energy K (or L) X-rays of the same material.

10. An apparatus in accordance with any one of claims 6 to 9 in which the radioisotope is selected from the group consisting of Gadolinium-153, Europium-155, Samarium-145, Iodine-125, Thulium-170 or Americium-241.

11. An apparatus in accordance with any one of claims 6 to 10 in which the shield is placed in front of the radioisotope source and the secondary emitting material is in the form of a hollow truncated cone, the narrow end of which is situated behind the radioisotope source and the inclined portions extend beyond the shield.

12. A method of producing X-rays of particular wave lengths substantially as described.

13. An apparatus for producing X-rays of particular wave lengths substantially as described with reference to and as illustrated in the accompanying drawings.

14. A method for the measurement of the thickness of coatings or for analysis of the constituents of a material in which an X-ray beam is projected onto the coating or the material and the intensity of the emergent beam is measured characterized in that as X-ray beam there is employed an X-ray beam produced by the method in accordance

with any one of claims 1 to 5 or 12 or using the apparatus as claimed in any one of claims 6 to 11 or 13.

15. A method according to claim 14 applied to the measurement of coating thickness.

16. An apparatus for the measurement of the thickness of coatings or for analysis of the constituents of a material comprising the apparatus as claimed in any one of claims 6 to 11 or 13, together with means for measuring the intensity of the emergent beam when the X-ray beam is projected onto the coating or the material.

17. An apparatus according to claim 16, when used for the measurement of coating thickness.

18. A method for the measurement of the thickness of coatings or for analysis of the constituents of a material substantially as described with reference to the Examples.

19. Apparatus for the measurement of the thickness of coatings or for analysis of the constituents of a material substantially as described with reference to Figure 4 of the accompanying drawings and the examples.

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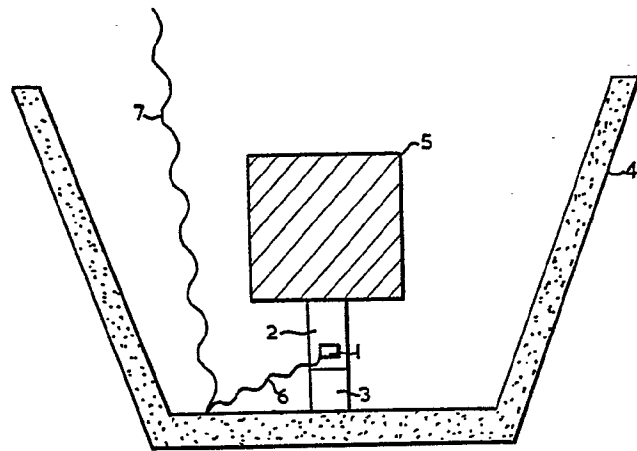


FIG. 1

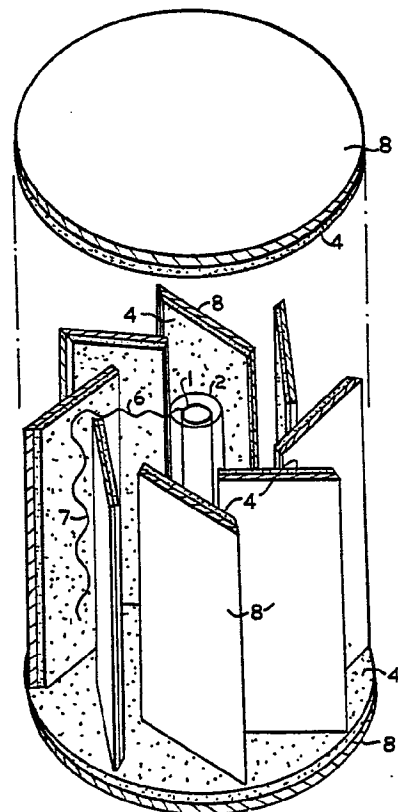


FIG. 2

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COMPLETE SPECIFICATION

2 SHEETS

*This drawing is a reproduction of
the Original on a reduced scale*

Sheets 1 & 2

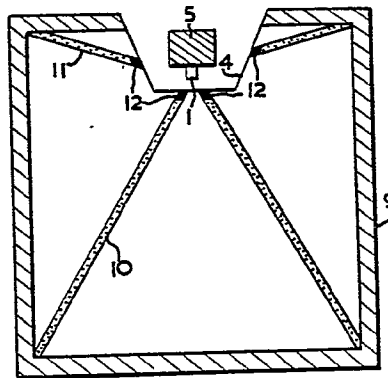
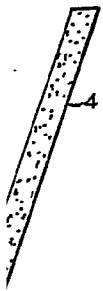


FIG. 3

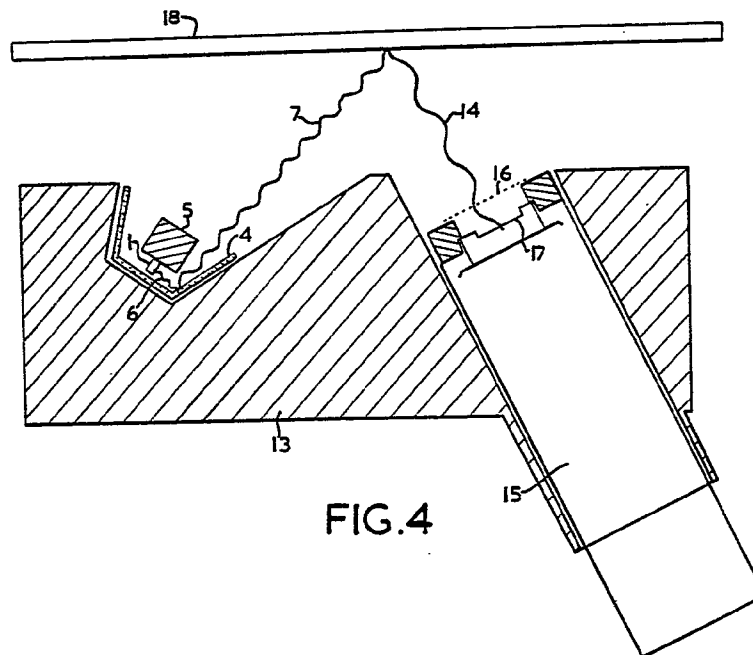


FIG. 4

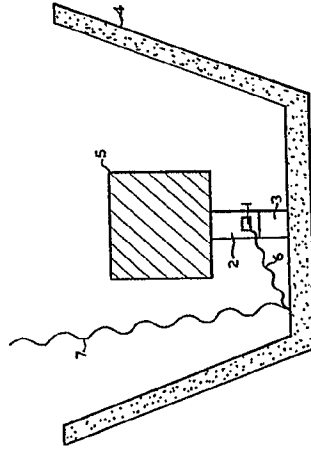
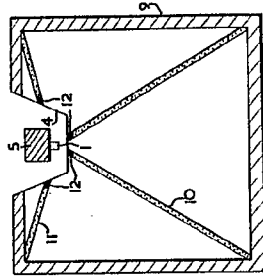


FIG. 1



3.6

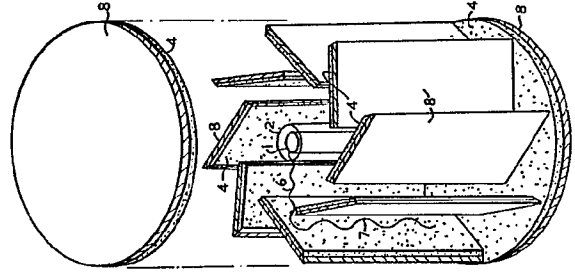


FIG. 2

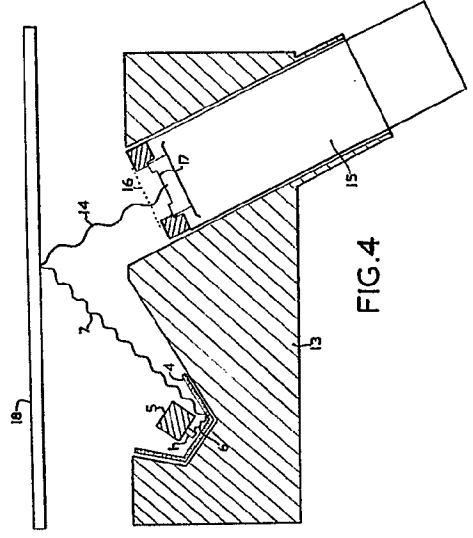


FIG. 4